(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 0 810 590 A2

(12) EUROPEAN PATENT APPLICATION

(43) Date of publication:
03.12.1997 Bulletin 1997/49

(51) Int Cl.[6]: G11B 7/24, G11B 7/09

(21) Application number: 97303518.1

(22) Date of filing: 22.05.1997

(84) Designated Contracting States:
DE FR GB

(30) Priority: 28.05.1996 US 654408

(71) Applicant: International Business Machines Corporation
Armonk, N.Y. 10504 (US)

(72) Inventors:
- Rosen, Hal Jervis
Los Gatos, California 95032 (US)
- Rubin, Kurt Allan
Santa Clara, California 95050 (US)
- Tang, Wade Wai-Chung
San Jose, California 95119 (US)

(74) Representative: Ling, Christopher John
IBM United Kingdom Limited,
Intellectual Property Department,
Hursley Park
Winchester, Hampshire SO21 2JN (GB)

(54) Optical data storage system with multiple rewritable phase-change recording layers

(57) A multiple recording layer rewriteable phase-change optical disk (12) and disk drive uses a reverse writing type of reversible phase-change material as the recording layer (53) nearest the incident laser light. The disk has a light-transmissive substrate (50) onto which the laser light is incident. The substrate supports at least two spatially-separated multilayer recording stacks (90, 92), each stack including an active recording layer (53, 64) of reversible or rewriteable phase-change material. The recording stack (90) located nearest the substrate (50) on which the laser light is incident includes a reverse writing type of reversible phase change material, i.e., a phase-change material with an amorphous starting phase that is recorded onto by laser heating that converts data regions to the crystalline phase. This first recording layer (50) has a dielectric layer (51) in contact with it that has a high index of refraction relative to the adjacent recording layer and that acts as an optical interference film to provide a constructive optical interference effect in the recording stack. The optical interference film optimizes the contrast, reflectivity, and transmissivity of the recording stack. The optical interference film is also nonabsorbing so that laser light can pass through it to focus on a recording layer (64) in a farther recording stack (92). This allows the farther recording layer to be written using reasonable laser power.

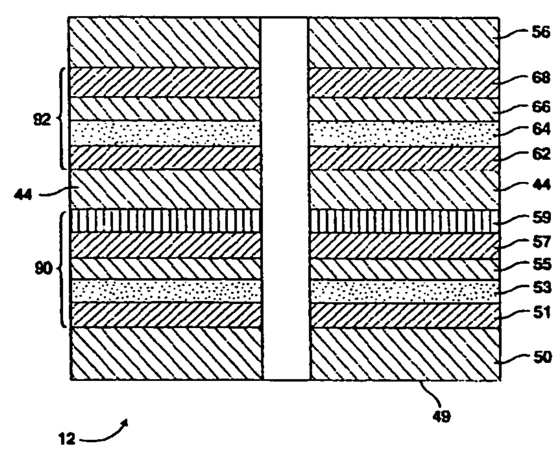

FIG. 5

EP 0 810 590 A2

Disclosure of the Invention

The invention is a multiple recording layer rewriteable phase-change optical disk and disk drive. The disk has a light-transmissive substrate onto which the laser light is incident. The substrate supports at least two spatially-separated multilayer recording stacks, each stack including an active recording layer of reversible or rewriteable phase-change material. The disk is either an air-gap structure wherein each recording stack is supported on a separate substrate and the substrates are separated by an air gap, or a solid structure wherein a solid light transmissive spacer layer separates the recording stacks. The recording stack located nearest the substrate on which the laser light is incident includes a reverse writing type of reversible phase change material (i.e., a phase-change material with an amorphous starting phase that is recorded onto by laser heating that converts data regions to the crystalline phase). This first recording layer has a dielectric layer in contact with it that has a high index of refraction relative to the adjacent recording layer and that acts as an optical interference film to provide a constructive optical interference effect in the recording stack. The optical interference film optimizes the contrast, reflectivity, and transmissivity of the recording stack. The optical interference film is also nonabsorbing so that laser light can pass through it to focus on a recording layer in a farther recording stack. This allows the farther recording layer to be written using reasonable laser power.

Brief Description of the Drawing

The invention will now be described, by way of example only, with reference to the accompanying drawings, in which.

Fig. 1 is a schematic diagram of an optical disk drive system of the present invention with a multiple recording layer rewriteable phase-change optical disk;

Fig 2A is a cross-soctional view of a dual substrate laminated multiple recording layer optical disk with rewriteable phase-change recording layers;

Fig 2B is a cross-sectional view of an air-gap multiple recording layer optical disk with rewriteable phase-change recording layers;

Fig 2C is a cross-sectional view of a single substrate laminated multiple recording layer optical disk with rewriteable phase-change recording layers;

Fig. 3 is a schematic diagram of the optical disk drive wherein the optical disk is in the form of a two-recording-layer air-gap structure;

Fig. 4 is a block diagram of a controller system of the optical disk drive system of the present invention;

Fig. 5 is a cross-sectional view of a dual substrate laminated multiple recording layer optical disk illustrating the multiple rewriteable phase-change recording layers with adjacent optical interference films according to a preferred embodiment of the present invention;

Fig. 6 is a graph of erasability, using pulsed erase, as a function of the erase power for the first data layer of a two-recording-layer disk according to the present invention;

Fig. 7A is a graph of readback data jitter and mark length as a function of laser write power for the first data layer of a two-recording-layer disk according to the present invention; and

Fig. 7B is a graph of readback data jitter and mark length as a function of laser write power for the second data layer of a two-recording-layer disk according to the present invention.

Detailed Description of the Invention

Fig. 1 is a schematic diagram of an optical disk data storage system according to the present invention designated by the general reference number 10. System 10 includes an optical data storage disk 12 having multiple recording layers. Disk 12 is preferably removably mounted on a clamping spindle 14 as is known in the art. Spindle 14 is attached to a spindle motor 16, which in turn is attached to a system chassis 20. Motor 16 rotates spindle 14 and disk 12.

An optical head 22 is positioned below disk 12. Head 22 is attached to an arm 24, which in turn is connected to

208. Beam 202 then passes through a focus lens 210 and is focused to a diffraction-limited spot onto one of the recording stacks 90, 92. Lens 210 is mounted in a holder 214, the position of which is adjusted relative to disk 12 by a focus actuator motor 216, which may be a voice coil motor. Movement of the lens 210 by the focus actuator motor 216 moves the focused spot between the two recording stacks 90, 92 on the substrates 50, 56 of disk 12.

In a conventional single recording layer rewriteable phase-change structure with a metallic heat dissipation reflective layer, the starting phase of the recording layer is crystalline and the recorded bits are in the amorphous phase with a lower reflectivity. However, in disk 12 of the present invention, the amorphous phase is chosen as the starting phase of the recording layer closest to the light source, i.e., in stack 90. The first recording stack 90 has a recording layer with an amorphous starting phase (recorded bits in the crystalline phase), while the second recording stack 92 can have a recording layer that has a crystalline starting phase (recorded bits in the amorphous phase). This is feasible provided there are header information bits stored in the respective recording stacks to inform the drive what reflectivity level of the recorded bits are in the respective recording stacks. The optical head must also be able to adjust the write pulse power level accordingly so as to have the capability of writing data bits on both the crystalline phase and amorphous phase. The use of a reverse writing (amorphous-to-crystalline phase) recording layer in the intermediate recording layers and conventional writing (crystalline-to-amorphous phase) in the farthest recording layer allows additional freedom in the design of high transmissive recording stacks with optimized signal-to-noise ratio on all recording layers, as will be described later.

Fig. 4 is a block diagram of a controller system of the optical disk drive system and is designated by the general reference number 300. The multielement detector 234 (Fig. 3) generates output signals that provide a data signal, a focus error signal (FES), and a tracking error signal (TES). The signals are amplified by signal amplifier 236. The data signal is sent to a PWM decoder 311 that generates the digital output data. The FES and TES are sent directly to controller 314. A peak detector 310 also receives the FES, and a peak detector 312 also receives the TES. Controller 314 also receives input signals from FES peak detector 310, TES peak detector 312, and laser power detector 207. Controller 314 is a microprocessor-based disk drive controller. Controller 314 is also connected to and controls laser modulator 252, laser driver 254, variable frequency clock 242, head motor 26, spindle motor 16, and focus actuator motor 216.

Fig. 2B is a cross-sectional view of a first alternative embodiment of a multiple recording layer recording disk 112 that may be substituted for disk 12 in system 10. Elements of disk 112 are similar to elements of disk 12 in Fig. 2A, but disk 112 does not have a solid spacer between substrates 190, 192. Instead, an air-gap 78 separates the substrates 150, 156. An outer diameter (OD) rim 152 and an inner diameter (ID) rim 154 are attached between substrates 150, 156. The OD and ID rims 152, 154 are preferably made of a plastic material and are approximately 50-300 microns thick. The rims 152, 154 may be attached to the substrates 150, 156 by glue, cement, ultrasonic bonding, solvent bonding, or other conventional bonding processes. The rims 152, 154 may alternatively be integrally formed in the substrates 150, 156 during the substrate molding process. When in place, the rims 152, 154 form the annular air-gap 78 between the substrates 150, 156. A spindle aperture 80 passes through disk 112 inside the ID rim 154 for receiving the spindle 14. A plurality of passages 82 are provided in the ID rim 154 to connect the aperture 80 and the spaces 78 to allow pressure equalization between the spaces 78 and the surrounding environment of the disk drive. A plurality of low impedance filters 84 are attached to passages 82 to prevent contamination of spaces 78 by particulate matter in the air. Filters 84 may be quartz or glass fibre. Alternatively, passages 82 and filters 84 can be located on the OD rim 152. The recording stacks 190, 192 on respective substrates 150, 156 contain the rewriteable phase-change recording layers, with stack 190 containing a recording layer formed of reverse writing phase-change material.

Fig. 2C is a cross-sectional view of a second alternative embodiment of a multiple recording layer disk 412 that may be substituted for disk 12 in system 10. Elements of disk 412 are similar to elements of disk 12 in Fig. 2A. However, disk 412 does not use two separate substrates as in the previous embodiments, but is a multilayer structure fabricated on a single substrate 450. The rewriteable phase-change recording stacks 490, 492 are separated by a solid spacer layer 422. Stack 490 contains a recording layer formed of reverse writing phase-change material. Spacer layer 422 is a light-transmissive layer formed by either lamination or deposition (such as a photo-polymer process or spin coating) over recording stack 490 on substrate 450. In a preferred embodiment, the light-transmissive spacer layer 422 is made of a polymer material such as photo-polymers. The top surface of layer 422 has tracking grooves and/or header information formed into its surface by either a photo-polymer process or embossing. The second rewriteable phase-change recording stack 492 is then deposited on top of spacer layer 422. A final protective layer 456 of polymer material, such as ultraviolet (UV) radiation curable spin-coated acrylate, or polycarbonate with adhesive coating, is then formed onto recording stack 492. Two disks like disk 492 can be bonded together with their respective layers 456 facing each other to make a two-sided disk. In this type of structure the two-sided disk is removed from the disk drive and flipped over so the drive can access the data layers on both sides.

The detailed description of the multiple rewriteable phase-change recording layers and their method of fabrication will be described below with respect to the disk structure of Fig. 2A. However, the multiple rewriteable phase-change recording layer system of the present invention is also operable with either of the other alternative disk structures

W/cm-K can be used for layer 51. For layers 55, 57, a thermal conductivity of larger than 0.01 is preferred. For example, SiO_x has a thermal conductivity of 0.015 W/cm-K at 400°K. Layer 59 serves the purpose of maximizing the optical interference effect of the recording stack 90 so it should have a high **k** value. Another function of the interference layer 59 is to optimize the reflectivity contrast of the recorded and nonrecorded regions of recording layer 53.

A solid spacer layer 44 is adjacent to the optical interference film 59 and separates the two recording stacks 90, 92. Spacer layer 44 is preferred to be nonabsorbing such as a spin-coated photo-polymer (UV-curable acrylate) or optical transparent cement that bonds the two substrates 50, 56 with their respective recording stacks 90, 92 together. The second recording stack 92 comprises a rigid transmissive dielectric layer 62 sputtered or evaporated on the second recording layer 64. Recording layer 64 is deposited on another rigid dielectric layer 66 which is adjacent to a heat dissipating layer 68 deposited on substrate 56. Since stack 92 is the last recording stack in the multiple recording layer optical disk and does not have to be light transmissive, a metallic film can be used for layer 68. With the use of a conventional heat dissipation layer 68, the composition and thickness of the second recording layer 64 has to be adjusted and will be different from the first recording layer 53. The stack 92 of second recording layer 64, dielectric layers 62, 66, and the metallic layer 68 are deposited on the second substrate 56. Substrate 56 can be formed of the same materials as substrate 50 or of opaque materials such as opaque plastic materials and metallic materials, such as aluminum.

In a preferred embodiment of optical disk 12, as shown in Fig. 5, with a laser operating at a 650 nm wavelength, substrates 50, 56 are polycarbonate of 0.6 mm thickness. First rigid dielectric layer 51 is znS or SiO_2, or a mixture of both, with a thickness of 70-150 nm. First recording layer 53 is $Ge_{11}Te_{47}Sb_{42}$ of 15 nm thickness. Dielectric layer 55 is ZnS or SiO_2, or a mixture of both, with a thickness of 10 nm. Thermal dissipation layer 57 is amorphous Si of thickness 50 nm. Optical interference film 59 is Si_3N_4 of thickness 60 nm. The transmissivity of the stack 90 with these layers is 31% when the recording layer 53 is in the amorphous (or unwritten) phase, and 15% in the crystalline (or written) phase. If conventional rewriteable phase-change materials (crystalline phase as the starting phase) were used as the recording layer in stack 90, the recording stack 90 would not have an acceptable transmissivity because the laser power required to write on the second recording stack 92 through stack 90 would be too high. However, the use of reverse writing phase-change material with an amorphous starting phase (recorded bits in crystalline phase) reduces the required laser power to write on the recording layer 64 in the farther recording stack 92. When data bits are written on the recording layer 53, the layer 53 is no longer totally amorphous. However, considering that the recording track width/track pitch is typically one half and that there are amorphous regions of bit spacing, even for a fully recorded layer, the percentage of the recording layer that is still in the amorphous phase would still be typically greater than 70%.

Such a reverse writing type of rewriteable phase-change recording structure with a transmissivity greater than 30% and a reflectivity greater than 10% is required for reliable operation with good signal to noise with existing laser diode sources. The spacer layer 44 is a UV-curable, spin-coated photo-polymer of 200 microns thickness. The dielectric layer 62 for the stack 92 is ZnS or SiO_2, or a mixture of both, with a thickness of 100 nm. The second recording layer 64 in stack 92 is formed of a conventional type of rewriteable phase-change material (a non reverse writing alloy of GeTeSb) with a 25 nm thickness. The second dielectric layer 66 is ZnS or SiO_2, or a mixture of both, with a thickness of 15 nm. The metallic heat dissipation layer 68 is Al of 100 nm thickness. If the laser light is of a shorter wavelength, to reduce the spot size and thereby increase the recording density, adjustment of the thickness of heat dissipation layer 57 and dielectric layer 59 is needed. For example, for laser light at a 500 nm wavelength, the thickness of layers 57, 59 is optimally at 25 nm and 65 nm, respectively.

In a particular example of a semitransparent recording stack 90 of a dual recording layer disk similar to the above-described preferred embodiment described and shown by Fig. 5, the recording layer 53 for recording stack 90 was formed of $Ge_{11}Te_{47}Sb_{42}$. The transparent dielectric layers 51, 55 were formed of SiO_2. Semitransparent heat dissipating layer 57 was formed of amorphous Si and the optical interference film 59 was formed of Si_3N_4. The stack 90 was deposited on a polycarbonate substrate 50. The dielectric layer 51 was sputter deposited to a thickness of 70 nm on substrate 50. The recording layer 53 was 15 nm thick and sputter deposited on layer 51. Second dielectric layer 55 of thickness 1 nm was sputtered on layer 53. Layer 57 was amorphous Si of thickness 50 nm sputtered on dielectric layer 55. The optical interference layer 59 was 75 nm thick and sputtered on dielectric layer 57. For the recording stack 92, the recording layer 64 was formed of a non reverse writing alloy of GeTeSb. The transparent dielectric layers 62, 66 were formed of a mixture of ZnS (80%) + SiO_2 (20%). Metallic heat dissipation layer 68 was formed of Al. The stack 92 was deposited on polycarbonate substrate 56. The two recording stacks 90, 92 had values of transmissivity, reflectivity, and absorption at 780 nm wavelength as shown in Table 1 below:

Table 1

Recording Stack (See Fig. 5)	Thickness (nm)	Transmissivity (%)	Reflectivity (%)	Absorption (%)
Stack 90	225	36	29	35
Stack 92	245	0	20	80

crystallization time is allowed since layer 64 has the benefit of an efficient heat dissipating metallic layer 68. These additional reverse writing materials include the materials described previously for use as the farther recording layer 64 but with compositions varied to provide the desired crystallization time.

The invention has been described in the embodiment of an optical disk drive. However, there are other types of optical data storage systems to which the invention is applicable. These systems usually have the feature that the medium upon which the data is stored can be removed. The common systems are those using optical media in the form of a tape or card. The drive associated with the tape or card moves the tape or card by translation, instead of rotation in the case of a disk, for the reading and writing of data. It is desirable to also increase the data storage capacity of optical tape and cards by the use of multiple recording layers of rewriteable phase-change material. In the optical tape or card, the multiple recording stacks may be supported on an opaque substrate and covered with a transparent protective layer onto which the laser light is incident. In this case, the protective layer functions like the previously described disk substrate. Both the tape or card protective layer and the disk substrate are transparent members that have an outer surface onto which the laser light is incident and through which the laser light travels to the recording stacks.

Claims

1. An optical data recording medium (12) comprising (a) a first light transmissive substrate (50) having a first surface (49) that forms an outer face for receipt of incident laser light and a second surface opposite said first surface; (b) a first recording layer (90) of reverse writing type of reversible phase-change material formed on the second surface of the first substrate and spaced from the substrate outer face by the thickness of the first substrate; (c) an optical interference film (51) in contact with the first recording layer and transmissive to the light, the optical interference film having an index of refraction significantly different from the index of refraction of the first recording layer and a thickness sufficient to provide constructive interference of the light, the first recording layer and the optical interference film in contact with it being light transmissive; and (d) a second recording layer (92) of reversible phase-change material spaced from the first recording layer.

2. An optical medium as claimed in claim 1 wherein the optical medium (12) is an optical disk.

3. An optical medium as claimed in claim 2 wherein the second recording layer (92) has an amorphous stating phase.

4. An optical disk as claimed in claim 2 further comprising a spacer layer (44) transmissive to the light and located between and separating the first (90) and second (92) recording layers by the thickness of said spacer layer.

5. An optical disk as claimed in claim 4 wherein the second recording layer (92) is formed on the spacer layer (44).

6. An optical disk as claimed in claim 2 further comprising a metallic light reflective film formed on and in contact with the second recording layer.

7. An optical disk as claimed in claim 2 further comprising a second substrate (156) and wherein the second recording layer (192) is formed on the second substrate and the first (150) and second substrates are spaced apart by an air gap (78).

8. An optical disk as claimed in claim 2 further comprising a dielectric layer formed on the surface of the substrate opposite the disk outer face for protecting the substrate during heating of the first recording layer, wherein the first recording layer is formed on and in contact with the dielectric layer on the substrate, and wherein the optical interference film is formed on and in contact with the first recording layer, the optical interference film having a thermal conductivity higher than that of the dielectric film formed on the substrate.

9. An optical disk as claimed in claim 2 further comprising a second optical interference film formed on and in contact with the first optical interference film.

10. The optical disk as claimed in claim 2 wherein the reversible phase-change material in the first layer (90) is an alloy having a composition of the form $Ge_xTe_ySb_z$ where $10<x<15$, $45<y<55$, $38<z<48$ and $x+y+z=100\%$.

11. The optical disk as claimed in claim 2 wherein the phase-change material in the second recording layer (92) comprises one or more materials selected from the group consisting of GeTe, SnTe, PbTe, SbSe, Sb_2Se_3, $Sb_{(1-x)}Se$

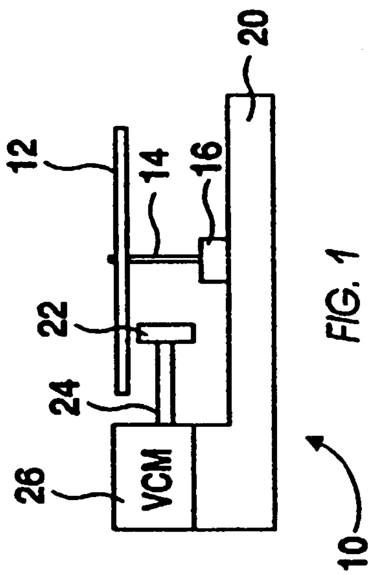
12
14
16
20
22
24
26
VCM
10

FIG. 1

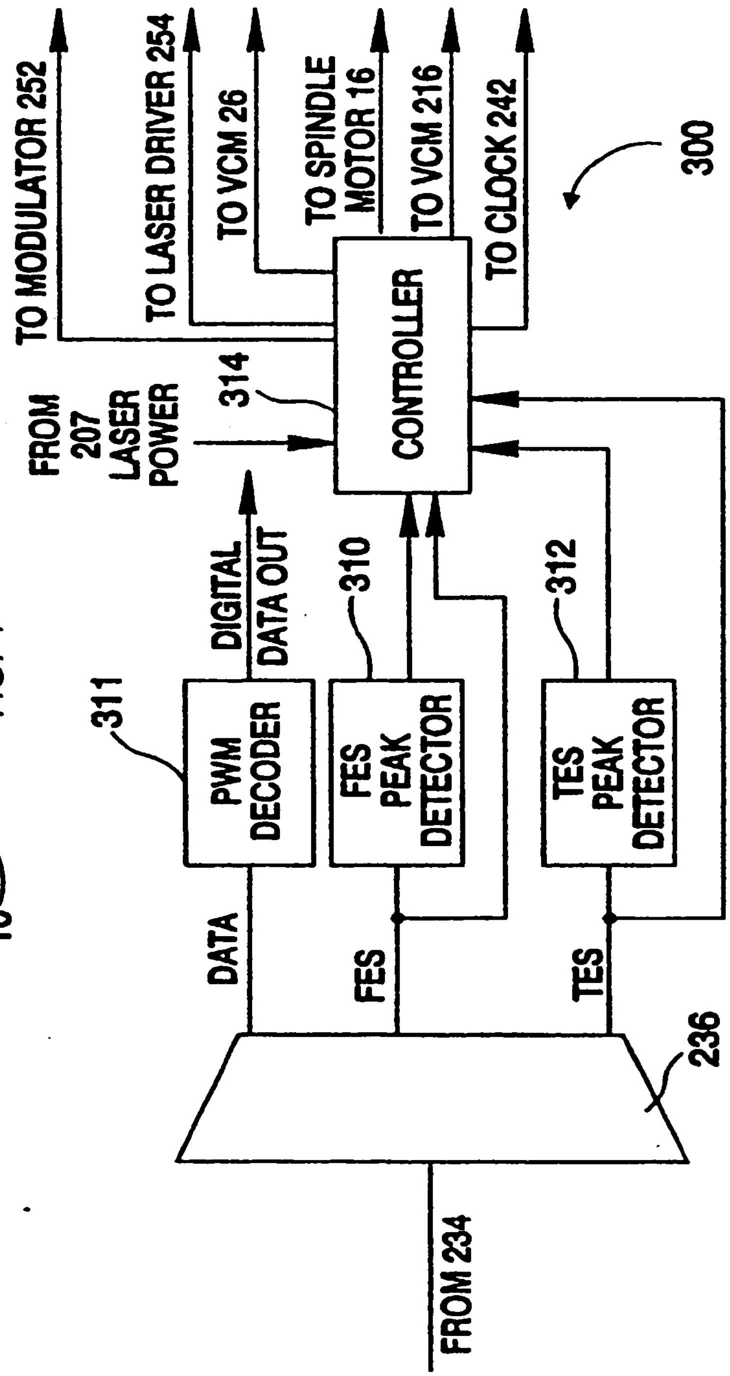
TO MODULATOR 252
TO LASER DRIVER 254
TO VCM 26
TO SPINDLE MOTOR 16
TO VCM 216
TO CLOCK 242
300
FROM 207 LASER POWER
314
CONTROLLER
DIGITAL DATA OUT
311
PWM DECODER
310
FES PEAK DETECTOR
312
TES PEAK DETECTOR
DATA
FES
TES
236
FROM 234

FIG. 4

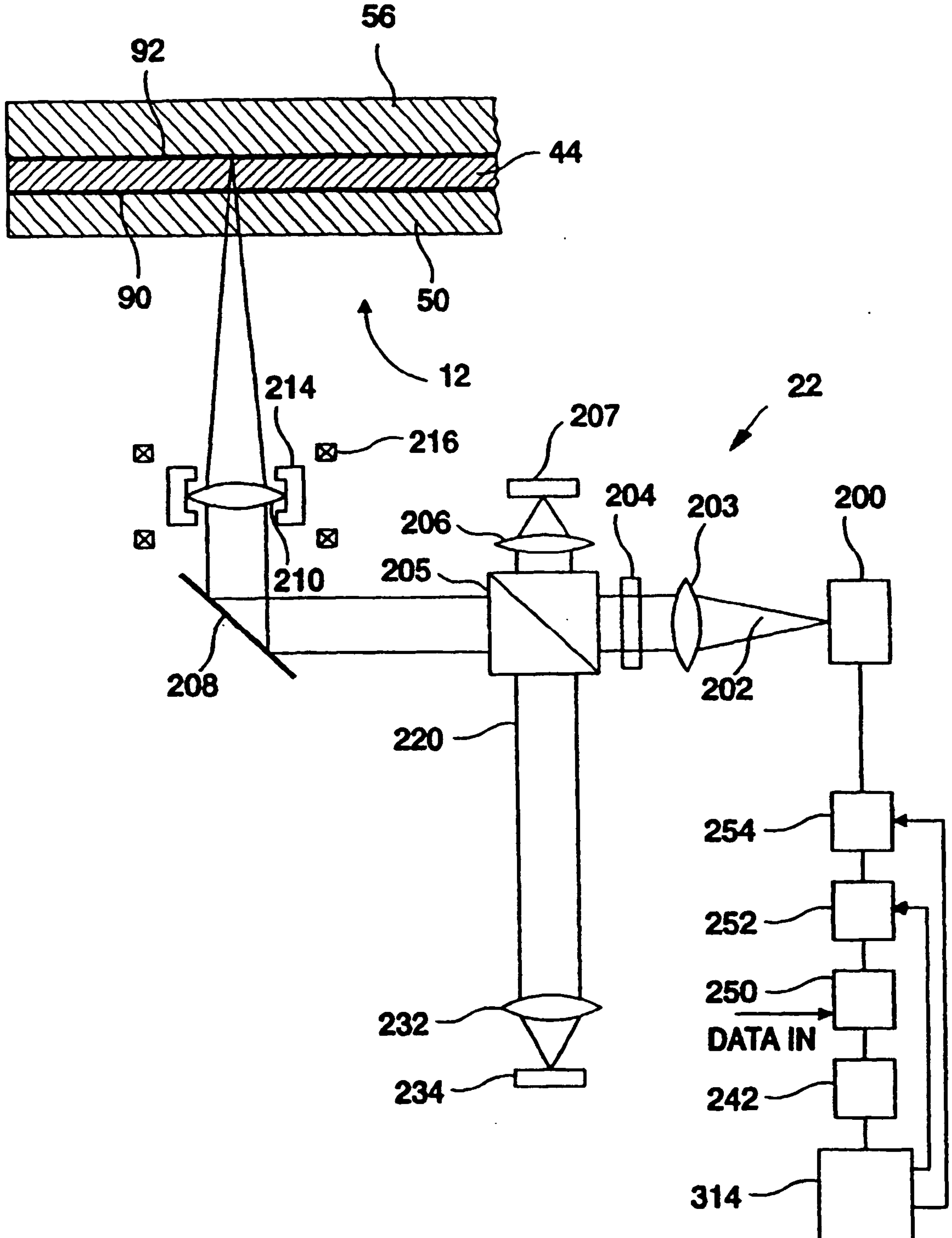
56
92
44
90
50
12
22
214
216
207
204
203
200
206
205
210
208
202
220
254
252
250
DATA IN
232
234
242
314

FIG. 3

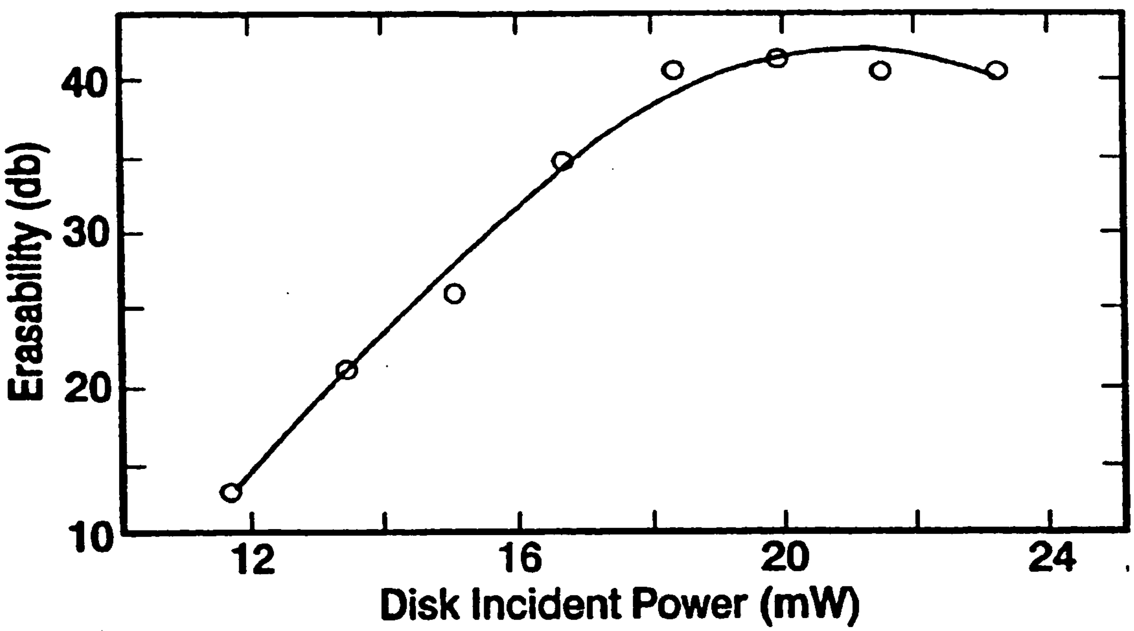

FIG. 6